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Fermilab

HEAT LEAK MEASUREMENTS ON FERMILAB'S ENERGY SAVER MAGNET STRING AND TRANSFER LINE

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Heat leak measurements on magnet strings and transfer line were taken during the latest run of the A1 and A2 satellite refrigerators this past summer. Methods and results are discussed in this report.

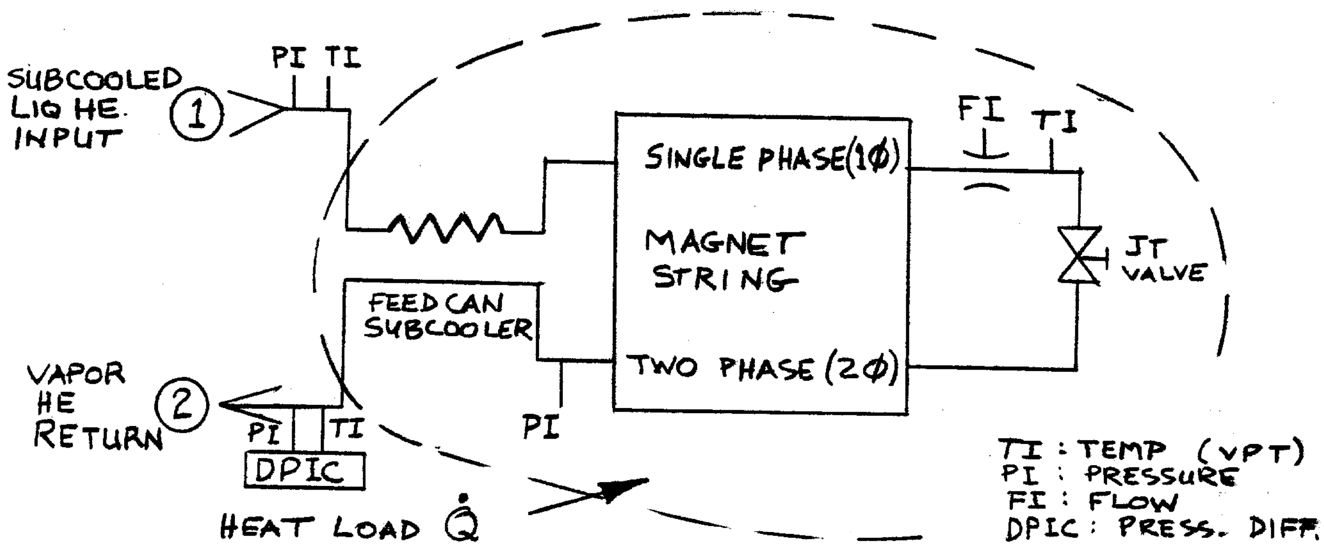

Figure 1. Magnet String Control Volume.

MAGNET TESTS

Figure 1 depicts the control volume for the upstream half (US) of 20 magnets, spool pieces, single turnaround box containing the Joule-Thomson (JT) valve, and the feed can with its helium subcooler. The downstream half (DS) looks similar, and can be operated independently.

Steady state heat leak measurements on the system shown in Fig.1 are based on the first law of thermodynamics;

$$Q = m \quad (H_2 - H_1)$$

where Q = heat input (watts)

m = mass flow rate (g/sec)

H_2 = enthalpy out (J/g) evaluated at pressure in the 2ϕ system degree superheat as indicated by the DPIC (pt 2)

H_1 = enthalpy in (J/g) evaluated at subcooled liquid helium supply (pt 1)

To make a reliable measurement,the inlet flow at pt.1 must be single phase (1∅) liquid, at least 1 psi (0.1^{o}K) subcooled. Exiting flow at pt. 2 must be superheated 0.1 to 0.3^{o}K, indicated by the DPIC when the VPT (vapor-pressure-thermometer) pressure is higher than the return gas pressure. (The reverse is true for subcooled liquid; the VPT pressure is lower than the existing local pressure). The test begins with the exiting flow being 2 ∅ (DPIC = 0). The mass flow rate is reduced by closing the JT valve until the DPIC reads a small positive pressure, indicating some superheat. States and properties at this point are used in the heat load calculations.

Results on He heat loads for upstream and downstream A2 magnet strings are summarized in Table 1 with a comment on the nature of each test. Under normal good vacumm ($<5 \times 10^{-7}$Torr), the heat load ranged from 113 to 152 watts. A very slow and accurate measurement on 9/25/80 showed heat loads of 146 to 151 watts. A test of the method of measurements was made with a known added heat load by applying electric power to the quench protection heaters mounted on the coils of each dipole magnet.

TABLE 1

Magnet Loop Heat Load Tests

RUN #	DATE	HEAT LOAD	COMMENTS
#(A)	04/30/80	US: 135 $\pm$ 15 W	DS failed to subcool.
#(B)	08/19/80	US: 114 W DS: 118 W	Good vacuum, calc @ sat vap. enthalpy at exit.
#(1)	09/03/80	US: 140 W	Good vacuum ($<10^{-7}$ Torr)
#(2)		US: 295 W	Shortly after He injection into magnet vacuum. Non-steady vacuum; pressure spikes. DPIC not zero at start.
#(3)	09/04/80	US: 137 W	7×10^{-6} Torr — 1 Ø boiled to 2 Ø before DPIC reacted, tests done too quickly, flow decreased too rapidly or too large of increments.
#(4)		161 W	6.0×10^{-5} Torr
#(5)		147 W	7.0×10^{-5} Torr
#(6)	09/05/80	US: 275 W	2.4×10^{-5} Torr — Flow rate controlled by bypass.
#(7)	09/06/80	US: 258 W	2.0×10^{-5} Torr
	Vacuum pumps valved off accidentally		
#(8)	09/09/80	US: 148 W	$<5 \times 10^{-7}$ Torr, wide vacuum variations.
#(9)	09/10/80	US: 151 W	$<5 \times 10^{-7}$ Torr.
#(10)		US: 149 W	$1. \times 10^{-5}$ Torr; DPIC = 0, but soon rose.
#(11)	09/11/80	US: 180 W	8×10^{-6} Torr
#(12)		US: 232 W	4×10^{-5} Torr
#(13)	09/12/80	US: 200 W	2.6×10^{-5} Torr; high W for DPIC =0.
#(14)	09/25/80	DS: 146 W	$<5 \times 10^{-7}$ Torr; very slow test.
#(15)		US: 151 W	$<5 \times 10^{-7}$ Torr; very slow test.
#(16)		US: 225 W	92 W added to He through quench protection heaters
#(17)		US: 226 W	92 W added to He through quench protection heaters

Our method registered a heat addition (to the magnets) of 75 to 83 watts while the actual power input through the heaters was 92 watts. These results are consistent with the estimated measurement error of 15 watts. Errors result from flow measurements and the dynamic nature of the test method, where pressures and flows are changing.

A series of tests were made on the upstream string of magnets at different magnet insulating vacuum pressures. In the control of insulating gas pressure, we chose to use helium gas in our measurement of the heat loss due to gas in the insulating vacuum space. Helium will not freeze out at the temperatures of the cold surfaces (70K and 4.5K) and condenses less than other gases under these condidions. Nevertheless we found that at 1.4×10^{-5} Torr helium pressure the amount of gas in the gas volume represented only 4.5% of the gas originally injected, while 95.5% must have condensed on the internal surfaces. All pumps were valved off during these observations. The gas was injected into the 400 ft. long string (of 16 dipoles, 4 quadrupoles and 4 spool pieces) at a point 100 ft. from the upstream end, called location A22. Fig. 2 shows how the gas spreads out and, at the same time, "disappears" due to adsorption over the next 11 hours.

The Penning type discharge gauges used for pressure measurement in the insulating vacuum space are less sensitive to helium than they are to nitrogen with which they are customarily calibrated. They indicate a pressure lower by a factor 5.5 when exposed to helium. The figures in Table 1 have already been corrected for this factor. The scale in Fig. 2 is uncorrected. All data points had a true helium pressure larger by a factor of 5.5 than indicated. No correction has been attempted for thermal transpiration, an effect on pressure readings when the gauge is at a temperature different from the one in the vessel of interest.

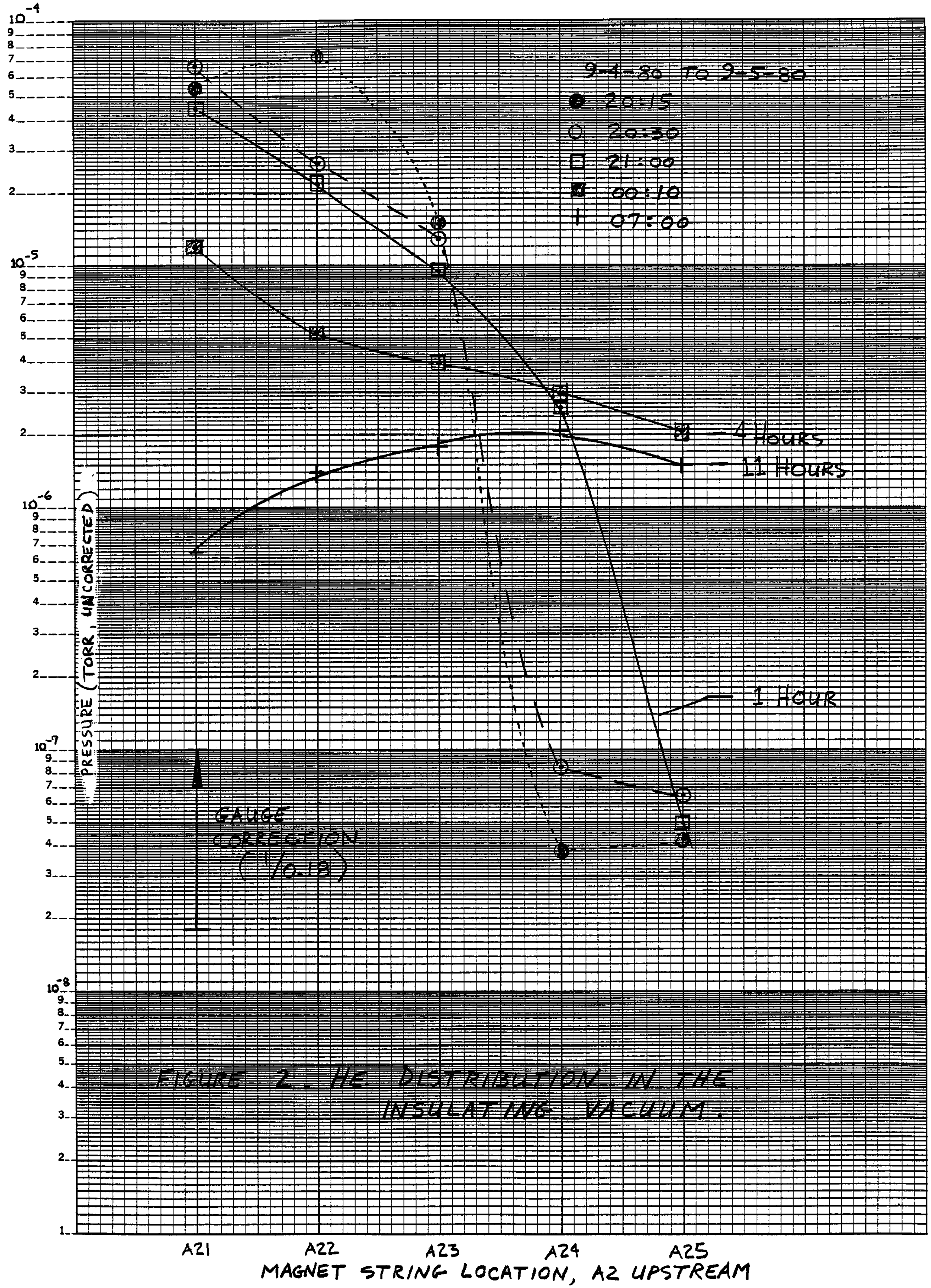

FIGURE 2. HE DISTRIBUTION IN THE INSULATING VACUUM.

The vacuum pressure is an important aspect in the magnet heat load. Figure 3 shows the results indicating that at pressures greater than 1×10^{-5} Torr the heat load begins to increase linearly with pressures due to conduction as predicted by theory. The heat load doubles for our magnets at a helium pressure (corrected) of $(4.5 \pm 2) \times 10^{-5}$ Torr in the insulating vacuum space; for nitrogen the heat load is then expected to double at 1.2×10^{-4} Torr. Table 1 explains the graphed point and reasons for some of the error bands.

TRANSFER LINE TESTS

Heat leak measurements were also made on both the N_2 shield and He supply of the 850 ft. transfer line between A1 and A2, Fig. 4. The A1 refrigerator operated in the liquefier mode and the A2 refrigerator in satellite mode, using A1 to simulate the central helium liquefier. Subcooled LN_2 was fed into the line and subcooled LN_2 exited at A2. Nitrogen heat loads of 140 ± 20 W were measured. This compares with tests made several months earlier that showed 165 W as compared to 180 w design value. Helium heat loads were measured with 9-10°K gas at various pressures. A measurement using supercritical helium was attempted but failed due to oscillations that appeared near the transfer line input. Early results showed a helium heat load of less than 11 W. The design helium heat load is 8 watts. Flow measurement and temperature discrepancies made accurate measurements difficult, see Fig. 5 A December run showed a 9 W $\pm$ 1 W He heat load on the transfer line, though flow measurement discrepancies still hampered a final heat leak number. Future test runs are planned to provide more helium heat leak data on the transfer line.

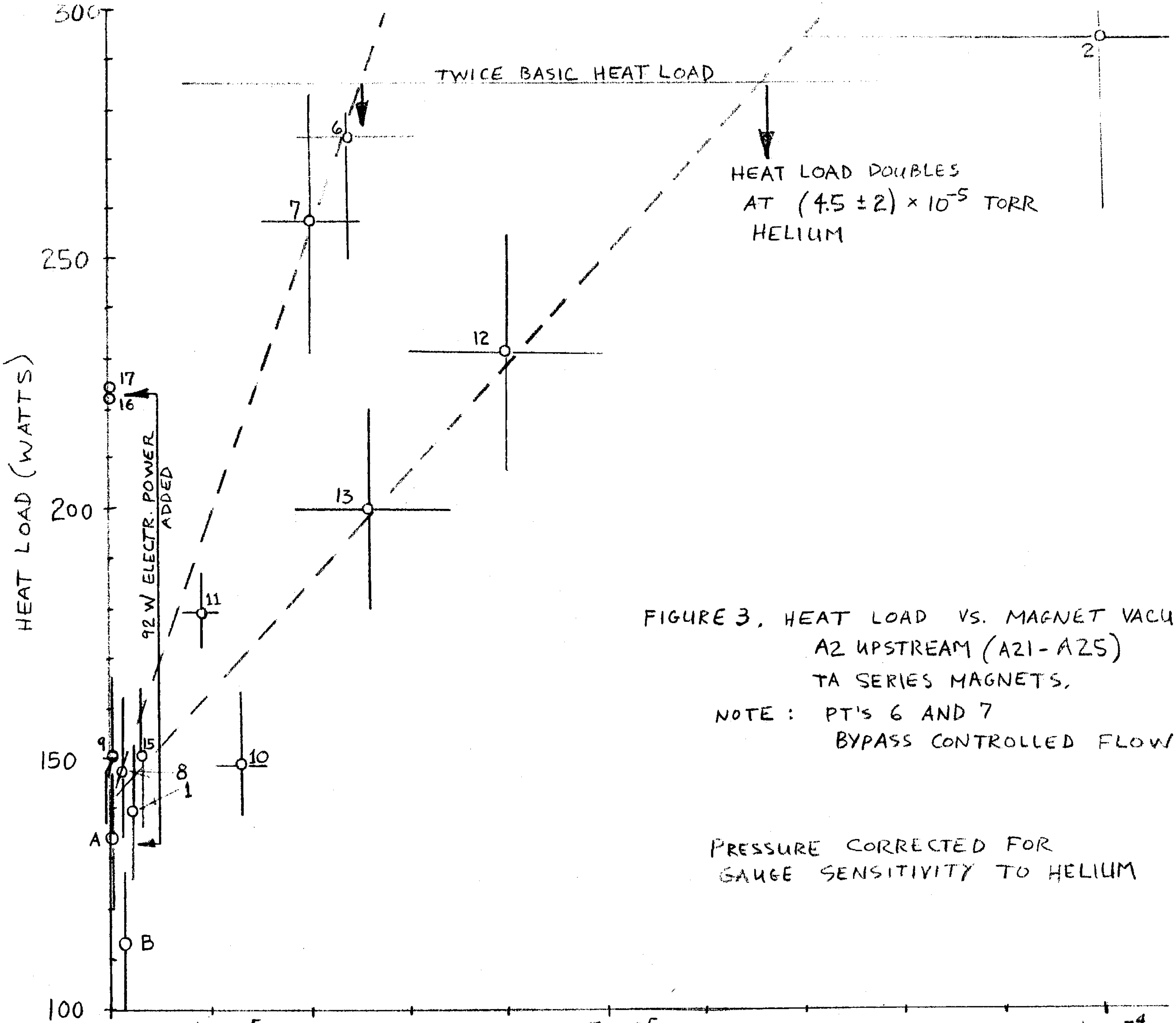

FIGURE 3, HEAT LOAD VS. MAGNET VACUUM
A2 UPSTREAM (A21 - A25)
TA SERIES MAGNETS.

NOTE : PT'S 6 AND 7
BYPASS CONTROLLED FLOW

PRESSURE CORRECTED FOR
GAUGE SENSITIVITY TO HELIUM

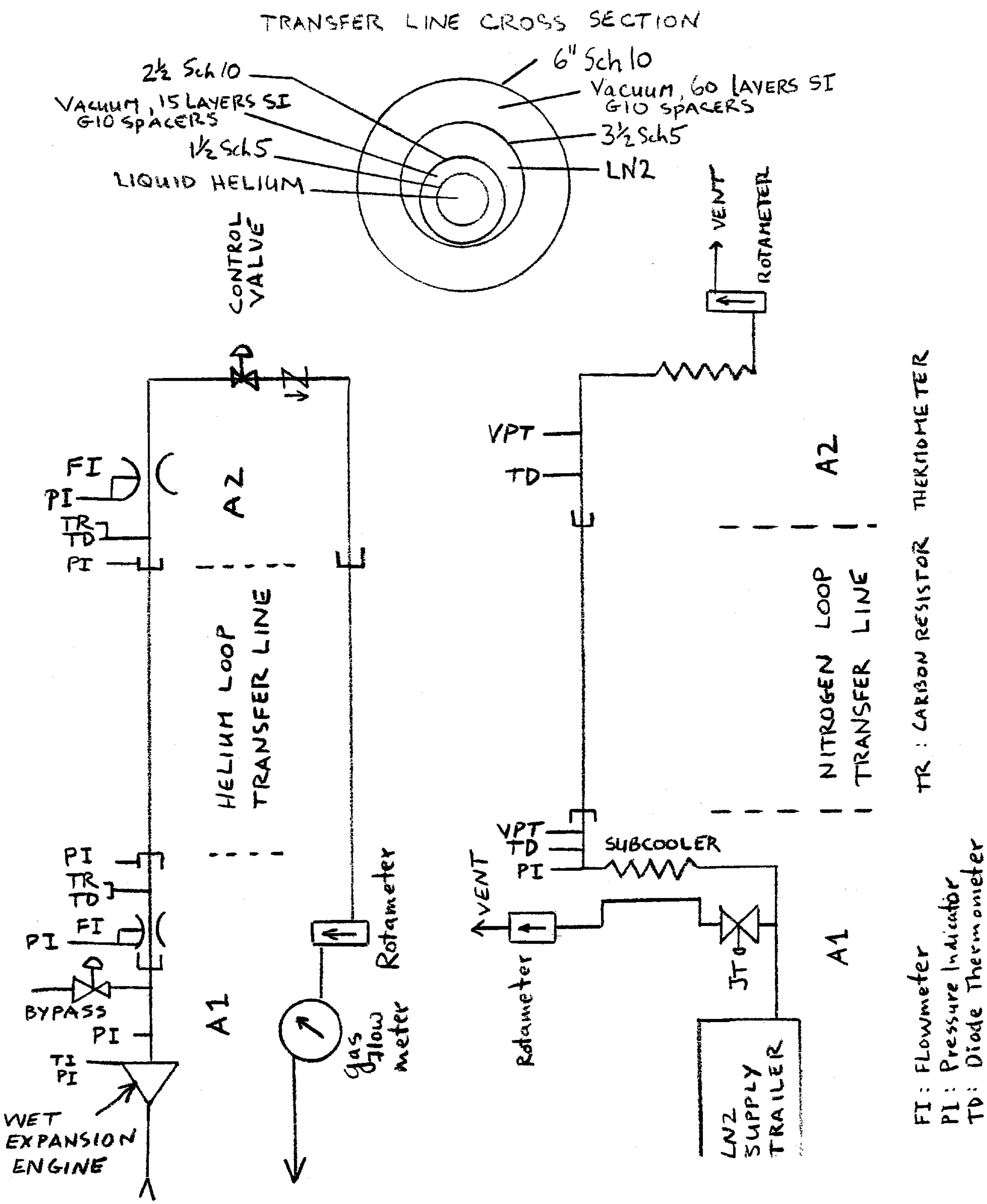

Figure 4. Transfer Line Heat Load Test.

TRANSFER LINE HELIUM HEAT LOAD (A-1, A-2)

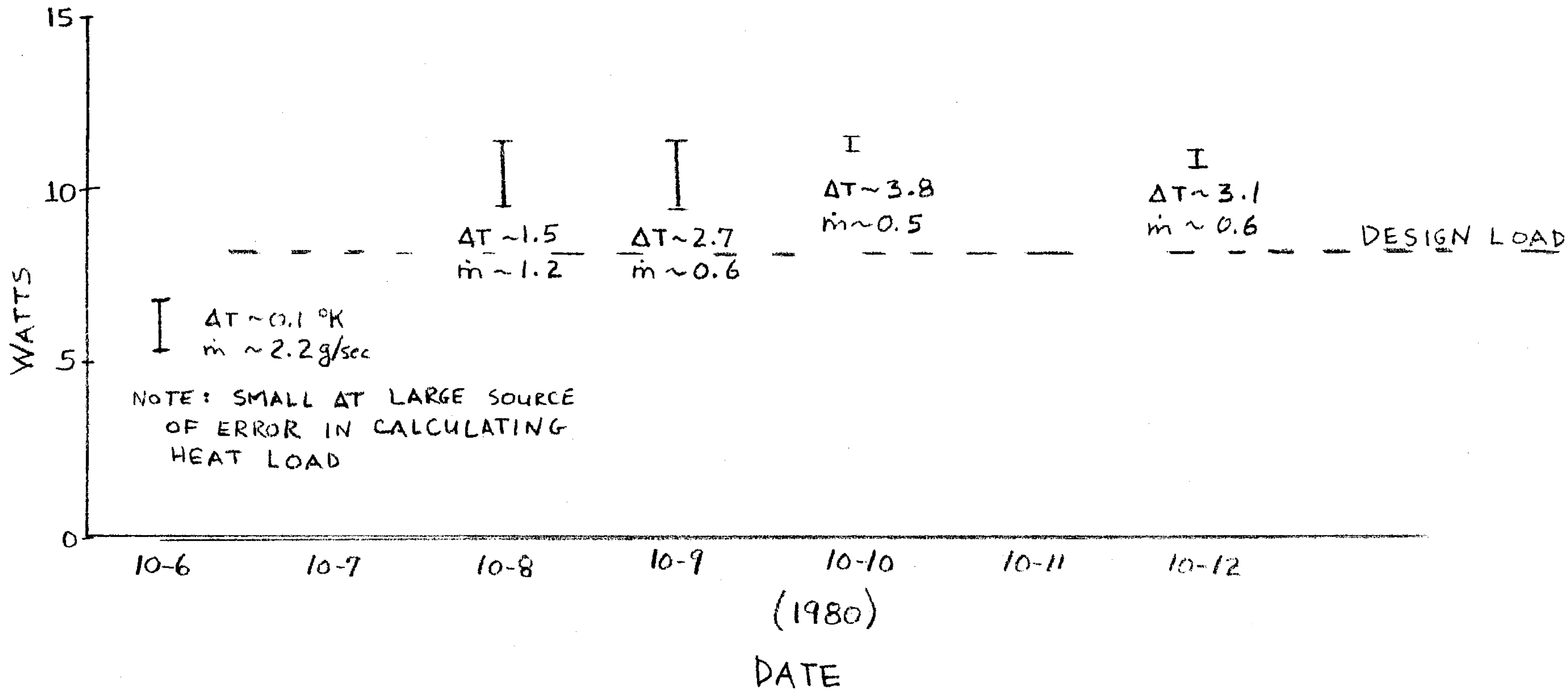

FIGURE 5. TRANSFER LINE HEAT LEAK FOR HELIUM.